Wood Beams: Materials & Beams

ARCHITECTURAL STRUCTURES:
Form, Behavior, and Design
ARCH 331
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FALL 2013

lecture
fifteen

wood construction:
Wood Beam Design

• National Design Specification
  – National Forest Products Association
  – ASD & LRFD (combined in 2005)
  – adjustment factors x tabulated stress = allowable stress
  – adjustment factors terms, C with subscript
  – i.e, bending:

\[ f_b \leq F'_b = F_b \times \left( \text{product of adjustment factors} \right) \]
Timber

- lightweight: strength ~ like steel
- strengths vary
  - by wood type
  - by direction
  - by “flaws”
- size varies by tree growth
- renewable resource
- manufactured wood
  - assembles pieces
  - adhesives
Wood Properties

• cell structure and density

http://www.swst.org/teach/set2/struct1.html
Wood Properties

• **moisture**
  – exchanges with air easily
  – excessive drying causes warping and shrinkage
  – strength varies some

• **temperature**
  – steam
  – volatile products
  – combustion

http://www.swst.org/teach/set2/struct1.html
Wood Properties

- **load duration**
  - short duration
    - higher loads
  - normal duration
    - > 10 years

- **creep**
  - additional deformation with no additional load
Structural Lumber

- **dimension** – 2 x’s (nominal)
- **beams, posts, timber, planks**
- **grading**
  - select structural
  - no. 1, 2, & 3
- **tabular values by species**
- **glu-lam**
- **plywood**
**Adjustment Factors**

- **terms**
  - $C_D = \text{load duration factor}$
  - $C_M = \text{wet service factor}$
  - $C_F = \text{size factor}$
    - visually graded sawn lumber and round timber > 12” depth

\[ C_F = \left( \frac{12}{d} \right)^{\frac{1}{9}} \leq 1.0 \]
Adjustment Factors

- **terms**
  - $C_{fu} = \text{flat use factor}$
    - *not decking*
  - $C_i = \text{incising factor}$
    - *increase depth for pressure treatment*
  - $C_t = \text{temperature factor}$
    - *lose strength at high temperatures*
Adjustment Factors

• terms
  – $C_r = \text{repetitive member factor}$
  – $C_H = \text{shear stress factor}$
    • splitting
  – $C_V = \text{volume factor}$
    • same as $C_F$ for glue laminated timber
  – $C_L = \text{beam stability factor}$
    • beams without full lateral support
  – $C_C = \text{curvature factor for laminated arches}$
Allowable Stresses

• design values
  – $F_b$: bending stress
  – $F_t$: tensile stress
  – $F_v$: horizontal shear stress
  – $F_{c\perp}$: compression stress (perpendicular to grain)
  – $F_c$: compression stress (parallel to grain)
  – $E$: modulus of elasticity
  – $F_p$: bearing stress (parallel to grain)
Load Combinations

• *design loads, take the bigger of*
  – (dead loads)/0.9
  – (dead loads + any possible combination of live loads)/\(C_D\)

• *deflection limits*
  – *no load factors*
  – *for stiffer members:*
    • \(\Delta_T\) max from \(LL + 0.5(DL)\)
Beam Design Criteria

• strength design
  – bending stresses predominate
  – shear stresses occur

• serviceability
  – limit deflection and cracking
  – control noise & vibration
  – no excessive settlement of foundations
  – durability
  – appearance
  – component damage
  – ponding
Beam Design Criteria

- superpositioning
  - use of beam charts
  - elastic range only!
  - "add" moment diagrams
  - "add" deflection CURVES (not maximums)

1. SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD

- Total Equiv. Uniform Load \( = w l \)
- \( R = V \) \( = \frac{wl}{2} \)
- \( V_x = w \left( \frac{l}{2} - x \right) \)
- \( M_{\text{max. (at center)}} = \frac{wl^2}{8} \)
- \( M_x = \frac{wx}{2} (l-x) \)
- \( \Delta_{\text{max. (at center)}} = \frac{5wx^4}{384EI} \)
- \( \Delta_x = \frac{wx^3}{24EI} (l^2 - 2lx^2 + x^4) \)
Beam Deformations

- curvature relates to
  - bending moment
  - modulus of elasticity
  - moment of inertia

\[
\frac{1}{R} = \frac{M}{EI}
\]

\[
\text{curvature} = \frac{M(x)}{EI}
\]

\[
\theta = \text{slope} = \int \frac{M(x)}{EI} \, dx
\]

\[
\Delta = \text{deflection} = \int \int \frac{M(x)}{EI} \, dx
\]
Deflection Limits

- based on service condition, severity

<table>
<thead>
<tr>
<th>Use</th>
<th>LL only</th>
<th>DL+LL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roof beams:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>L/180</td>
<td>L/120</td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>plaster ceiling</td>
<td>L/240</td>
<td>L/180</td>
</tr>
<tr>
<td>no plaster</td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td><strong>Floor beams:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ordinary Usage</td>
<td>L/360</td>
<td>L/240</td>
</tr>
<tr>
<td>Roof or floor (damageable elements)</td>
<td>L/480</td>
<td></td>
</tr>
</tbody>
</table>
Lateral Buckling

• lateral buckling caused by compressive forces at top coupled with insufficient rigidity
• can occur at low stress levels
• stiffen, brace or bigger $I_y$
### Table 9.3 Lateral bracing requirements for timber beams.

<table>
<thead>
<tr>
<th>Beam Depth/Width Ratio</th>
<th>Type of Lateral Bracing Required</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 1</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>3 to 1</td>
<td>The ends of the beam should be held in position</td>
<td><img src="image" alt="End blocking" /> Joist or beam</td>
</tr>
<tr>
<td>5 to 1</td>
<td>Hold the compression edge in line (continuously)</td>
<td><img src="image" alt="Sheathing or decking" /> Nailing Joist or rafter</td>
</tr>
<tr>
<td>6 to 1</td>
<td>Diagonal bracing should be used</td>
<td><img src="image" alt="Nailed sheathing/decking" /> Bridging Joist</td>
</tr>
<tr>
<td>7 to 1</td>
<td>Both edges of the beam should be held in line</td>
<td><img src="image" alt="Nailed sheathing/decking" /> top and bottom Bridging Joist</td>
</tr>
</tbody>
</table>

**Timber Beam Bracing**

*Wood Beams 18 Lecture 15*
*Architectural Structures ARCH 331*
Design Procedure

1. Know \( F_{all} \) for the material or \( F_U \) for LRFD

2. Draw \( V \) & \( M \), finding \( M_{\text{max}} \)

3. Calculate \( S_{\text{req'd}} \) \( \left( f_b \leq F_b \right) \)

4. Determine section size

\[ S = \frac{bh^2}{6} \]
Beam Design

4*. Include self weight for $M_{\text{max}}$
   - and repeat 3 & 4 if necessary

5. Consider lateral stability

Unbraced roof trusses were blown down in 1999 at this project in Moscow, Idaho.

Photo: Ken Carper
Beam Design

6. Evaluate shear stresses - horizontal

- \( f_v \leq F_v \)
- rectangles and W's \( f_{v-\text{max}} = \frac{3V}{2A} \approx \frac{V}{A_{\text{web}}} \)
- general \( f_{v-\text{max}} = \frac{VQ}{Ib} \)
Beam Design

7. Provide adequate bearing area at supports

\[ f_p = \frac{P}{A} \leq F_p \]
Beam Design

8. Evaluate torsion

\[ f_v \leq F_v \]

- circular cross section
  \[ f_v = \frac{T \rho}{J} \]
- rectangular
  \[ f_v = \frac{T}{c_1 ab^2} \]

**TABLE 3.1. Coefficients for Rectangular Bars in Torsion**

<table>
<thead>
<tr>
<th>a/b</th>
<th>c_1</th>
<th>c_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.208</td>
<td>0.1406</td>
</tr>
<tr>
<td>1.2</td>
<td>0.219</td>
<td>0.1661</td>
</tr>
<tr>
<td>1.5</td>
<td>0.231</td>
<td>0.1958</td>
</tr>
<tr>
<td>2.0</td>
<td>0.246</td>
<td>0.229</td>
</tr>
<tr>
<td>2.5</td>
<td>0.258</td>
<td>0.249</td>
</tr>
<tr>
<td>3.0</td>
<td>0.267</td>
<td>0.263</td>
</tr>
<tr>
<td>4.0</td>
<td>0.282</td>
<td>0.281</td>
</tr>
<tr>
<td>5.0</td>
<td>0.291</td>
<td>0.291</td>
</tr>
<tr>
<td>10.0</td>
<td>0.312</td>
<td>0.312</td>
</tr>
<tr>
<td>∞</td>
<td>0.333</td>
<td>0.333</td>
</tr>
</tbody>
</table>
**Beam Design**

9. **Evaluate deflections**

\[ y_{\text{max}}(x) = \Delta_{\text{actual}} \leq \Delta_{\text{allowable}} \]
Decking

- **across beams or joists**
- **floors: 16 in. span common**
  - ¾ in. tongue-in-groove plywood
  - 5/8 in. particle board over ½ in. plywood
  - hardwood surfacing
- **roofs: 24 in. span common**
  - ½ in. plywood
Joists & Rafters

- allowable load tables (w)
- allowable length tables for common live & dead loads
- lateral bracing needed
- common spacings
Engineered Wood

- plywood
  - veneers at different orientations
  - glued together
  - split resistant
  - higher and uniform strength
  - limited shrinkage and swelling
  - used for sheathing, decking, shear walls, diaphragms
Engineered Wood

- glued-laminated timber
  - glulam
  - short pieces glued together
  - straight or curved
  - grain direction parallel
  - higher strength
  - more expensive than sawn timber
  - large members (up to 100 feet!)
  - flexible forms
Engineered Wood

- **I sections**
  - beams

- **other products**
  - pressed veneer strip panels (Parallam)
  - laminated veneer lumber (LVL)

- **wood fibers**
  - Hardieboard: cement & wood
Timber Elements

• stressed-skin elements
  – modular built-up “plates”
  – typically used for floors or roofs

Figure 1. Typical Two-Sided Stressed-Skin Panel

- Plywood splice plate
- Vent holes
- Lumber header may be continuous or as shown on opposite end
- Scarf joint in lower skin is preferred method (alternate: spliced butt joint)
- Lumber stringers
- Lumber blocking (not required if pre-spliced skins are used)
Timber Elements

- built-up box sections
  - built-up beams
  - usually site-fabricated
  - bigger spans
Timber Elements

- **trusses**
  - long spans
  - versatile
  - common in roofs
Timber Elements

• folded plates and arch panels
  – usually of plywood
Timber Elements

• arches and lamellas
  – arches commonly laminated timber
  – long spans
  – usually only for roofs
Approximate Depths

FIGURE 15-3  Approximate span ranges for timber systems.